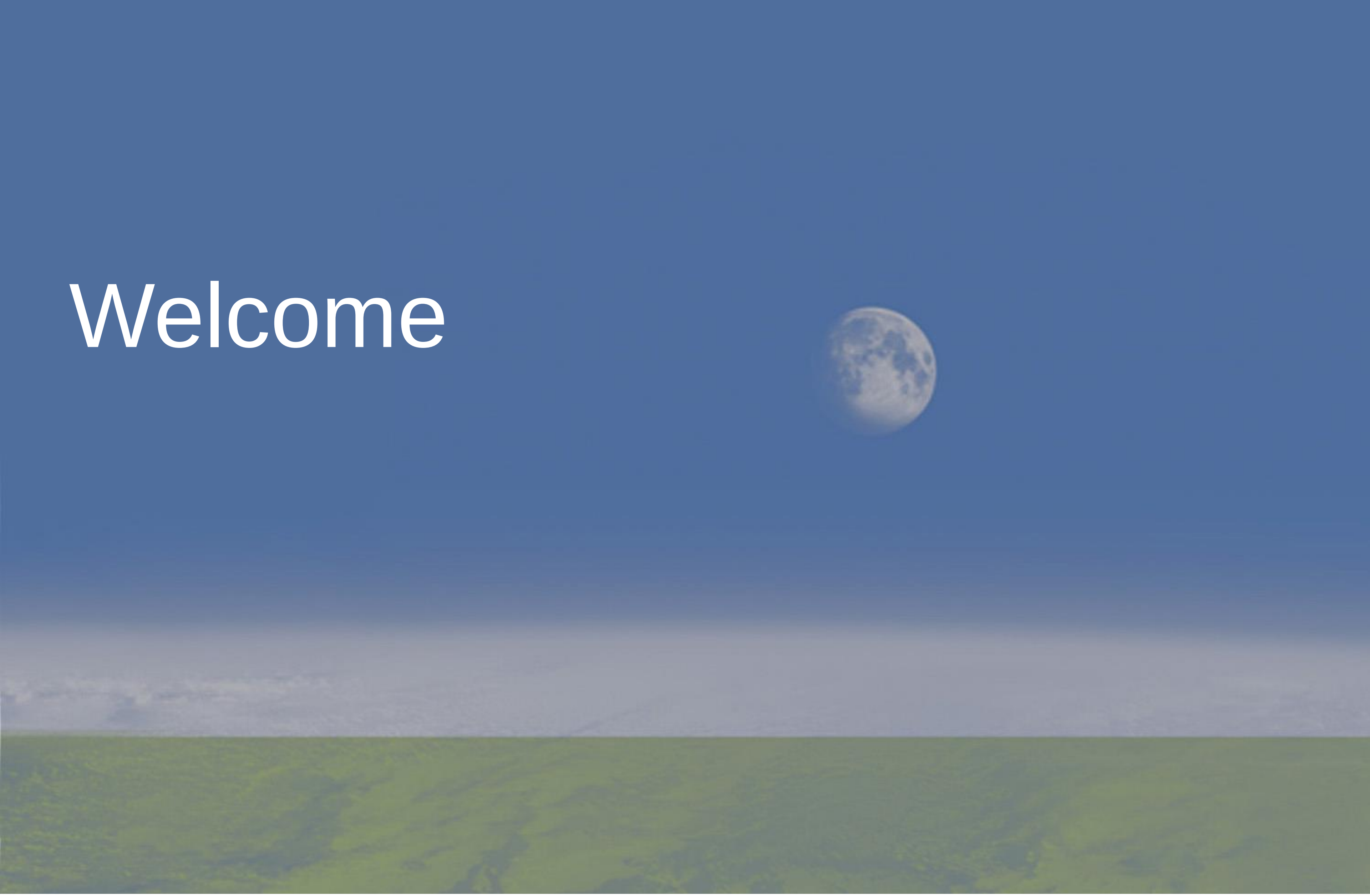
Welcome



Planetary Lander
Landing Stability Mechanics
for Lateral Motion

Gary M Ortiz
Laura Redmond
Jet Propulsion Laboratory
California Institute of Technology

Spacecraft Structures and Dynamics Group
Spacecraft Mechanical Engineering Section
Mechanical Systems Engineering, Fabrication and Test Division
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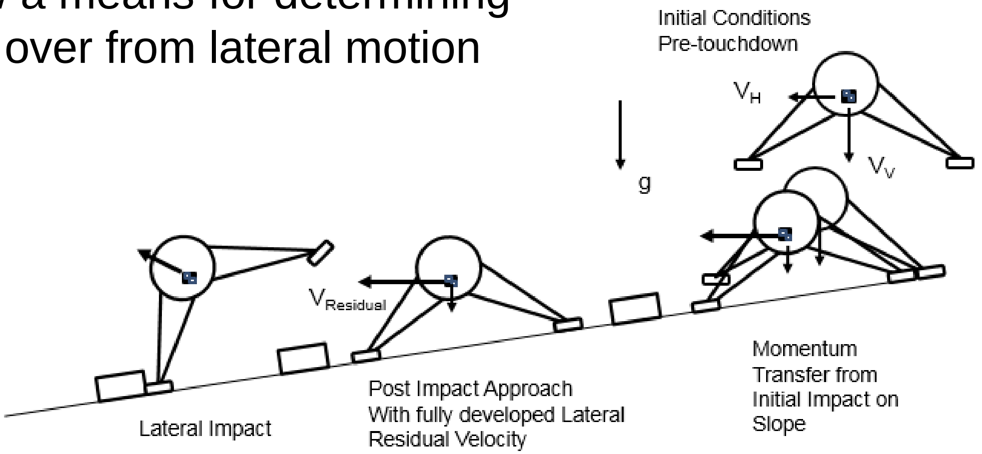
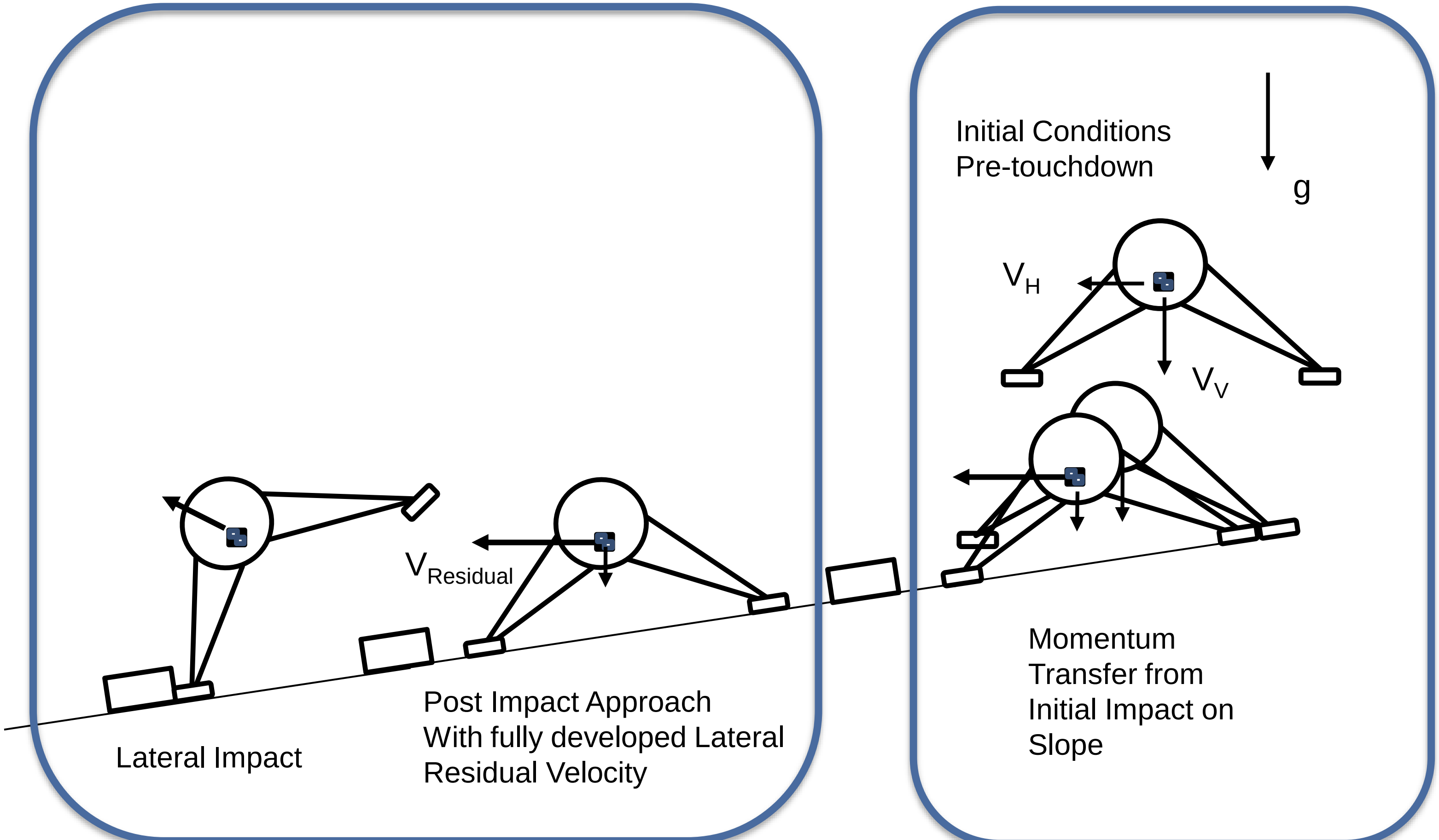
Assuring Space Mission Success

Overview

- A challenge for planetary lander design and analysis post initial impact is lateral stability threat
- If the lateral residual velocity is great enough, the lander will be subjected to pitching over by impacting obstacles in it path
- Sources for lateral velocities:
  - *Lateral velocity requirements from project*
    - Knowledge of lateral drift during descent
    - Knowledge of lateral wind velocity
  - *Momentum transfer from slope Impact*
- The following discussion will show a means for determining robustness of a lander to pitching over from lateral motion



Lateral Motion Post Initial Impact

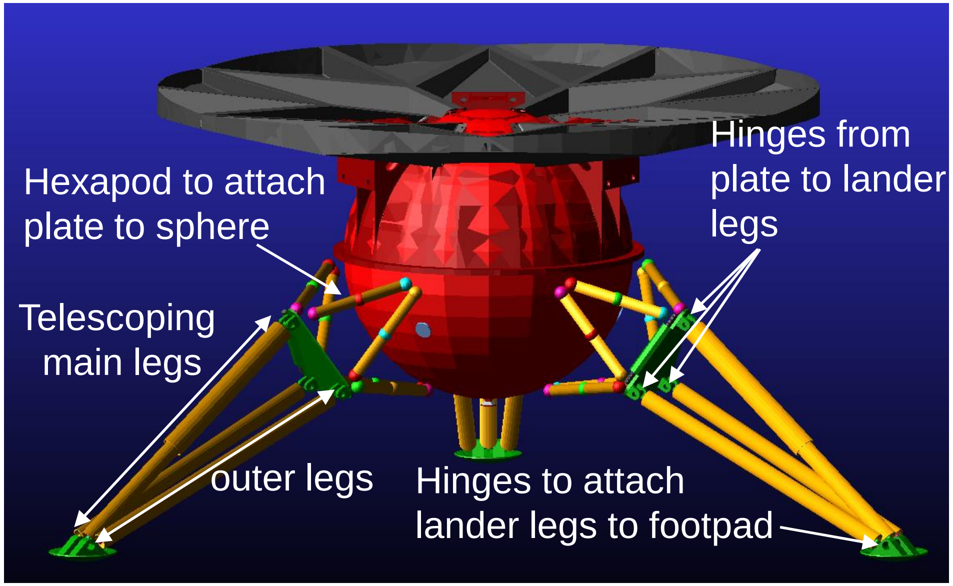


Second Impact Mechanics:
more challenging: addressing loads and stability for this phase usually lags in the design process

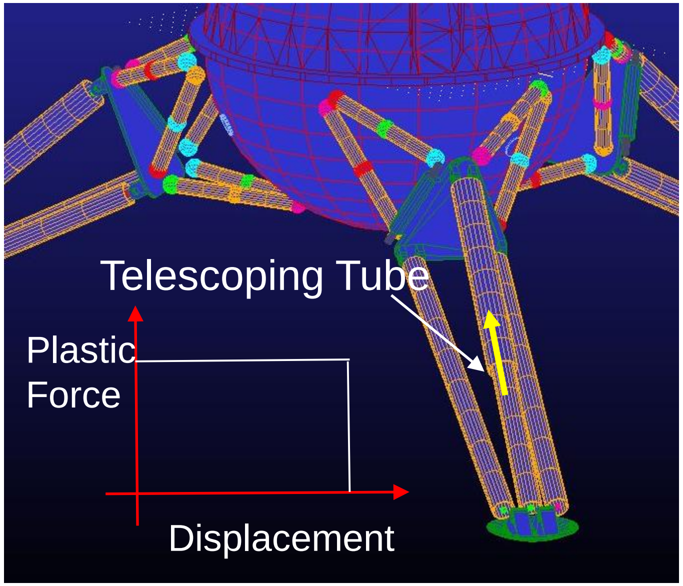
First Impact Mechanics: well understood

Simulation of Planetary Lander using ADAMS

- ADAM used to simulate impacts and stability
- Rigid: sphere, drag plate, triangular plates, footpads
- Flexible: beam members with degraded stiffness to account for temperature effects
- Crushable material in main lander tube for energy dissipation
- Landing surface modeled as rigid with obstacles



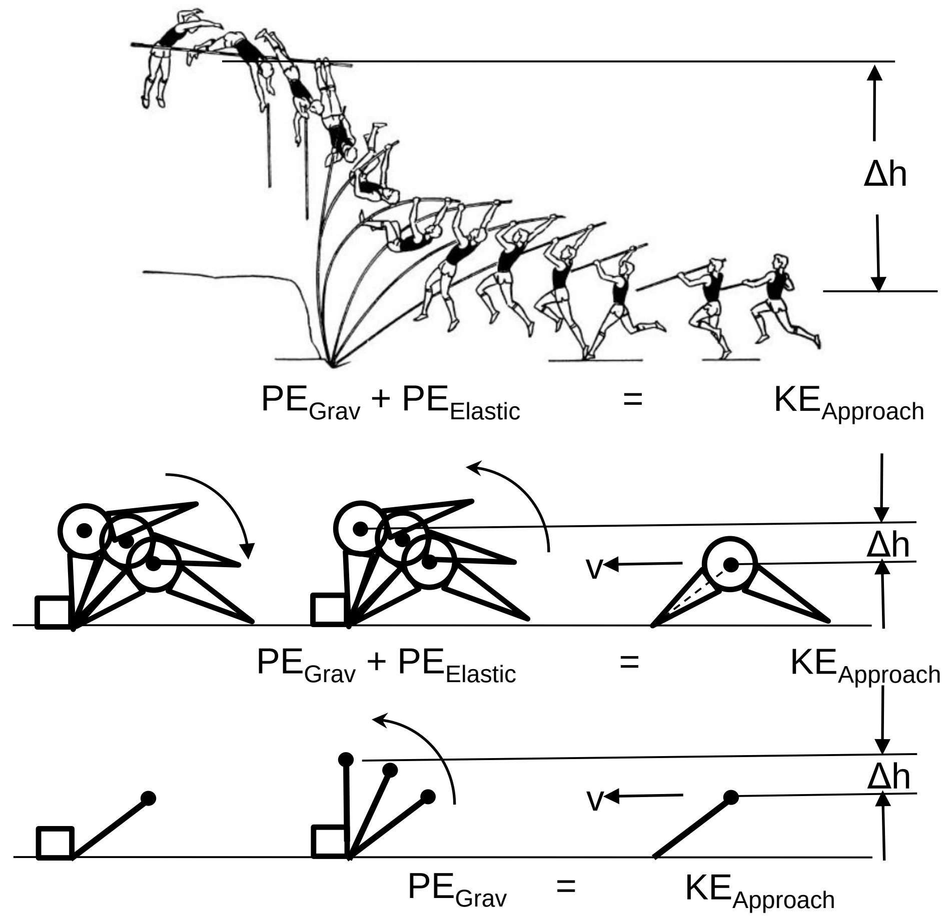
ADAMS model of the lander



Idealization of Crushable

Pole Vaulting Analogy

- The mechanics of the sport of Pole Vaulting and Spacecraft subjected to lateral motion are similar from a mechanics perspective, but have different goals:
  - *The Pole Vaulter requires:*
    - Levels of approach kinetic such that an adequate amount of kinetic energy is available at the end of the vault to **go over the bar**
  - *The Lander requires:*
    - Levels of approach kinetic energy such that all is converted into gravitational potential energy such that the **lander can recover safely on the approach side of the obstacle**
- The goal is to have a means to determine how much approach velocity can be tolerated such that all the kinetic energy is converted to potential energy and the lander can recover safely:



Idealization of Lander Model

Mechanics: Safe Velocity for Lateral Motion Robustness

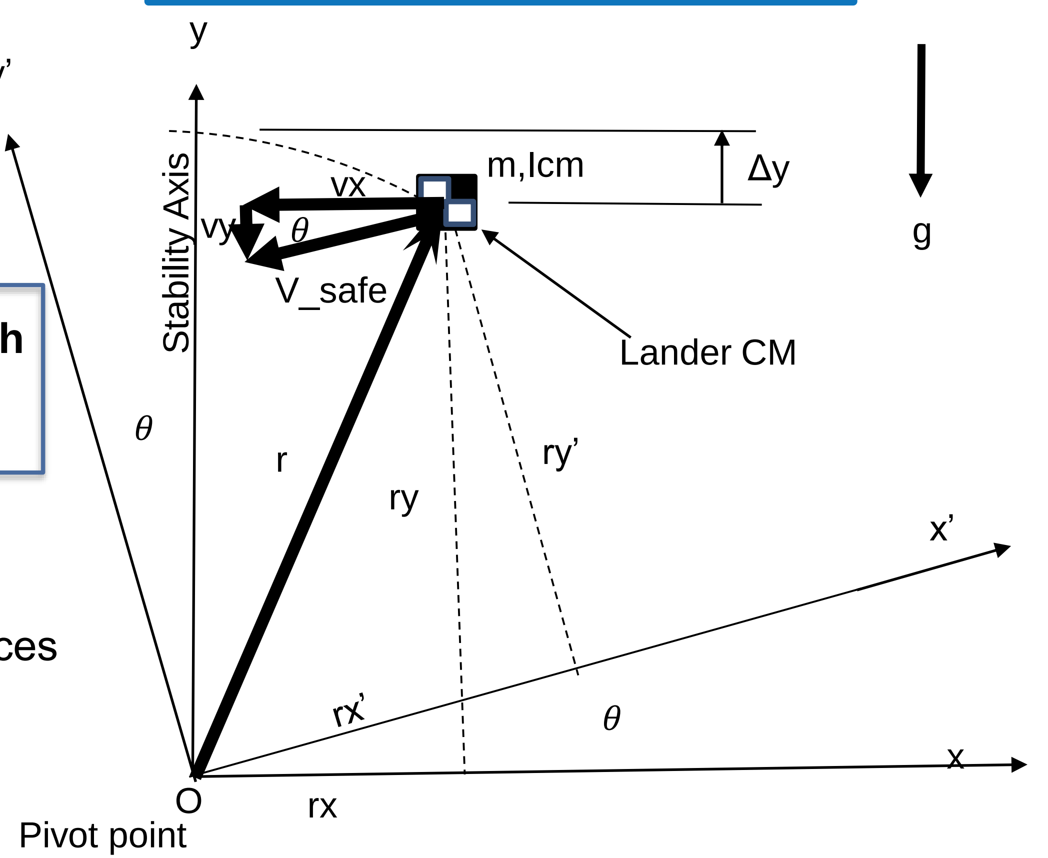
Stability Robustness of a lander design can be measured by how much lateral velocity can be tolerated at impact

$$V_{safe} = \frac{1}{mry'}\sqrt{2mg\Delta y I_o}$$

From rigid body mechanics, the velocity, ***V_safe,*** can be derived from familiar conservations laws of: Energy and Momentum

V_safe: Maximum approach velocity such that all kinetic energy is converted into gravitational potential energy

r: distance from pivot to lander CM
ry’: Normal distance to cm from surface
rx’: distance from pivot of hard-stop to cm
Δy: Maximum vertical distance mass displaces
θ: Slope angle
m: mass
Icm: Centroidal moment of inertia
Io: Moment of inertia about point o
g: gravity



Reference Frame Model

Mechanics: Safe Velocity Determination

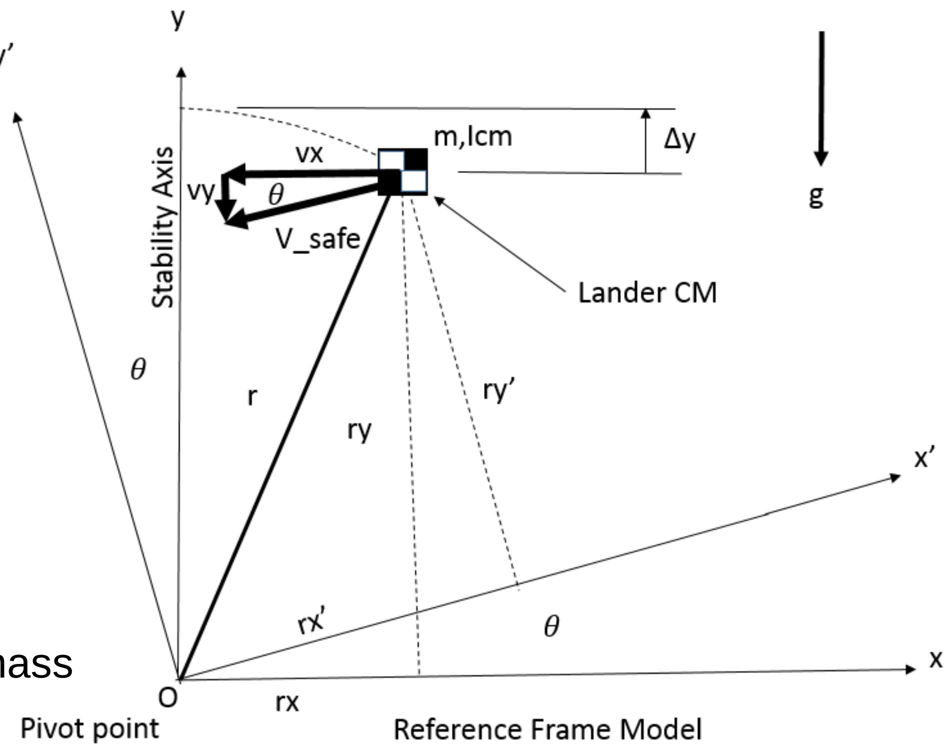
- V_{safe} is a measure of robustness of a lander to tip over and should be maximized
- V_{safe} highly dependent on lander geometry and mass distribution:

$$V_{safe} = \frac{1}{mry'}\sqrt{2mg\Delta y I_o}$$

Minimize ry' for larger V_{safe}

Maximize potential by maximizing Δy

Maximize mass distribution



To maximize V_{safe} → **Minimize CM height Maximize Footprint**

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Calculation of Vsafe:

- Excerpt from spread sheet for Vsafe calculation as a function of Slope angle:

mass(kg)	Icm(kg-m^2)	gravity (m/s^2)	ry' , vertical distance to cm normal to surface (m)	rx' distance parallel to surface from cm to minimum footprint radius (m)	Slope Angle (deg)	
					0	

OUTPUT						
Apparent CM coordinates in x-y Csys		Distance r, magnitude (m)	Moment of Inertia from Pivot (kg-m^2)	Δy (m), Maximum distance work is done		V_SAFE (m/s)
ry(m)	rx(m)					
						3.1

Slope Angle (deg)	
5	
	V_SAFE (m/s)
	2.7

Slope Angle (deg)	
10	
	V_SAFE (m/s)
	2.3

Slope Angle (deg)	V_safe (m/s)
0	3.1
5	2.7
10	2.3

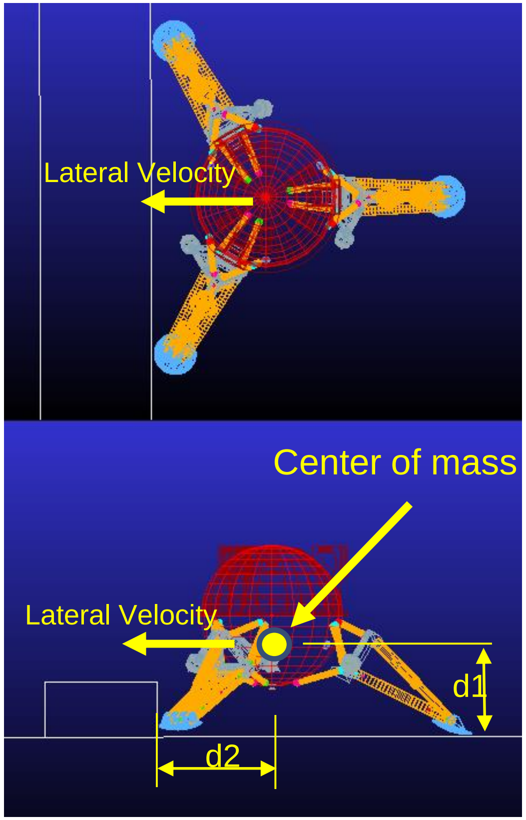
Overview

- Using ADAMS, landing stability for a 2 leg impact of hard-stop on a sloped surface will be shown

- The surface is rigid and has the following coefficients of friction: Static: 0.1; Dynamic: 0.05

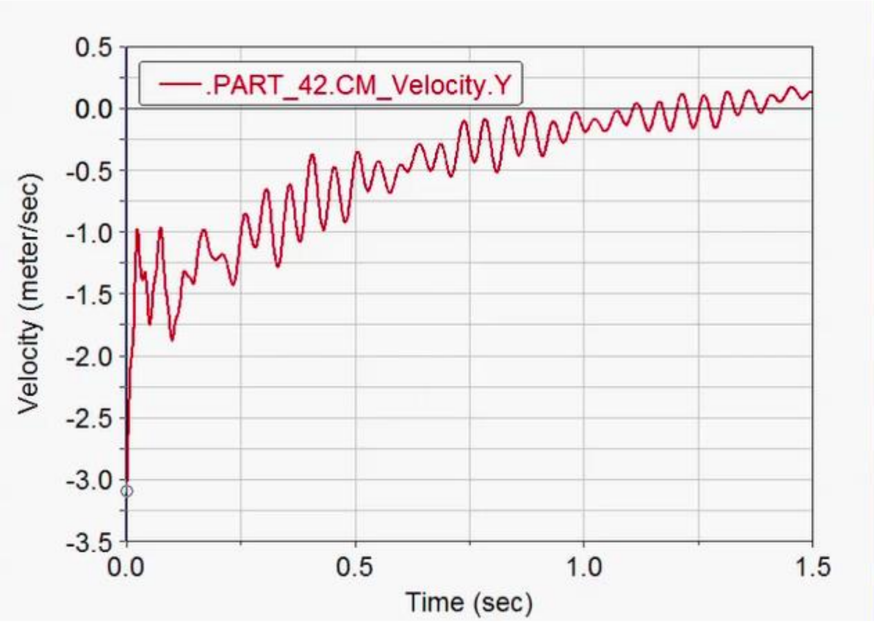
- From ADAMS a comparison of the lateral residual velocities from an impact will be compared to Vsafe

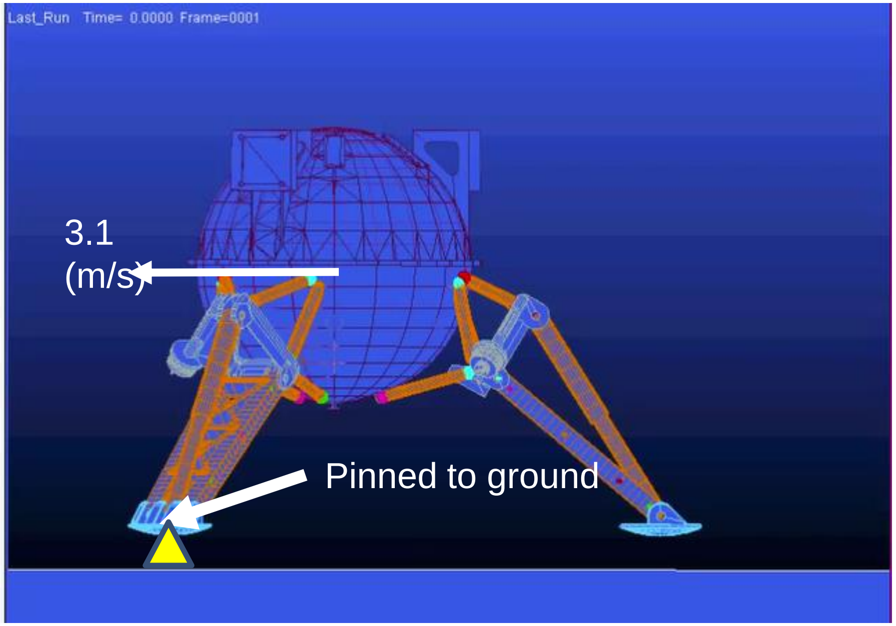
- d1 and d2 are locations from the pivot point of the hard stop to the lander center of mass



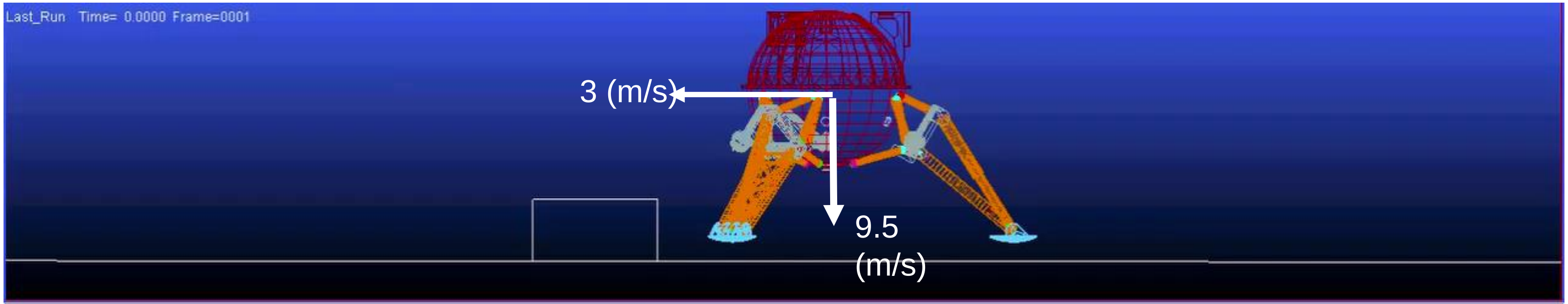
ADAMS Model variable definitions

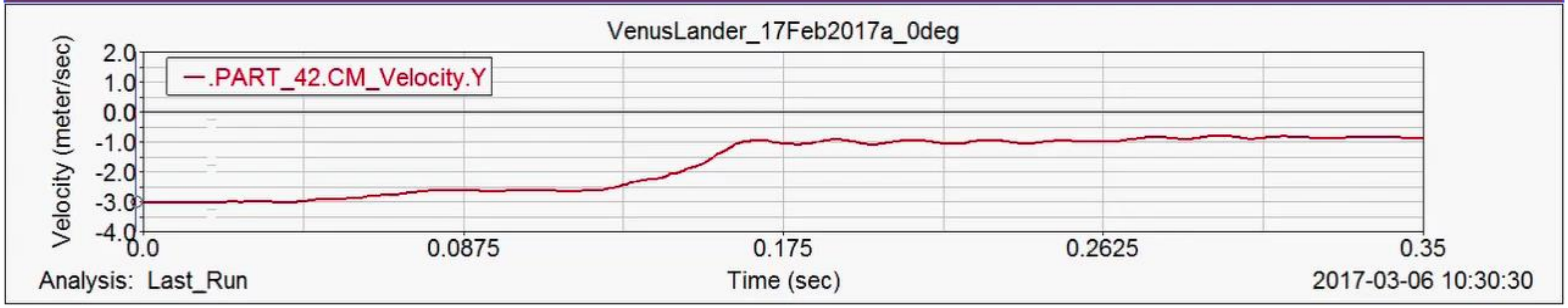
Case Study: Zero Slope; Pinned to Ground
Safe Velocity = 3.1 m/s



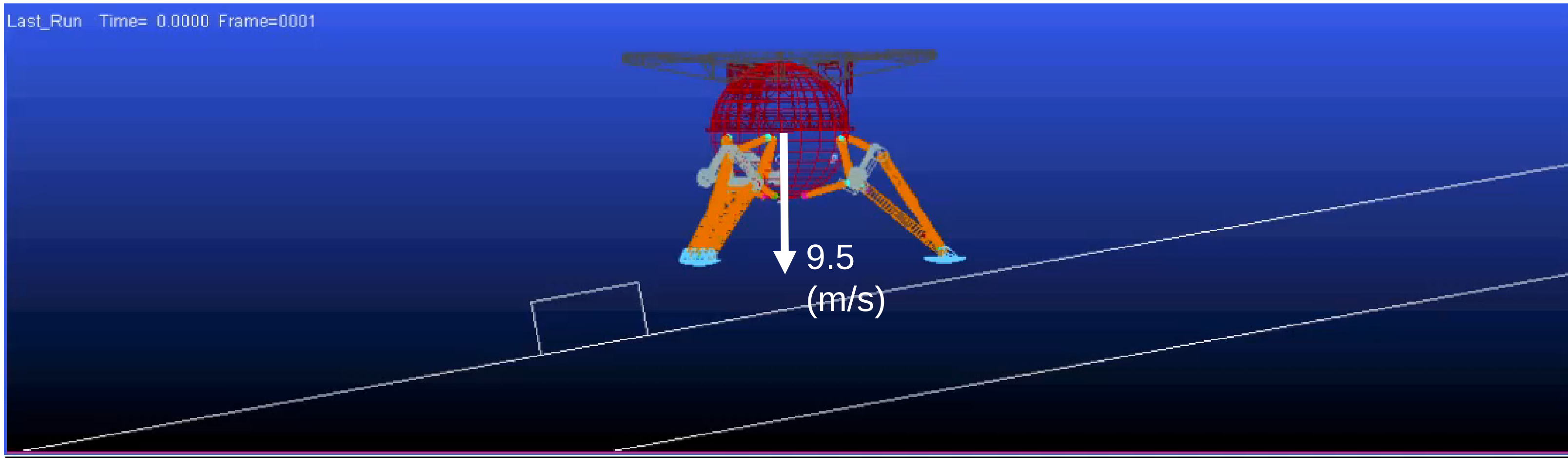


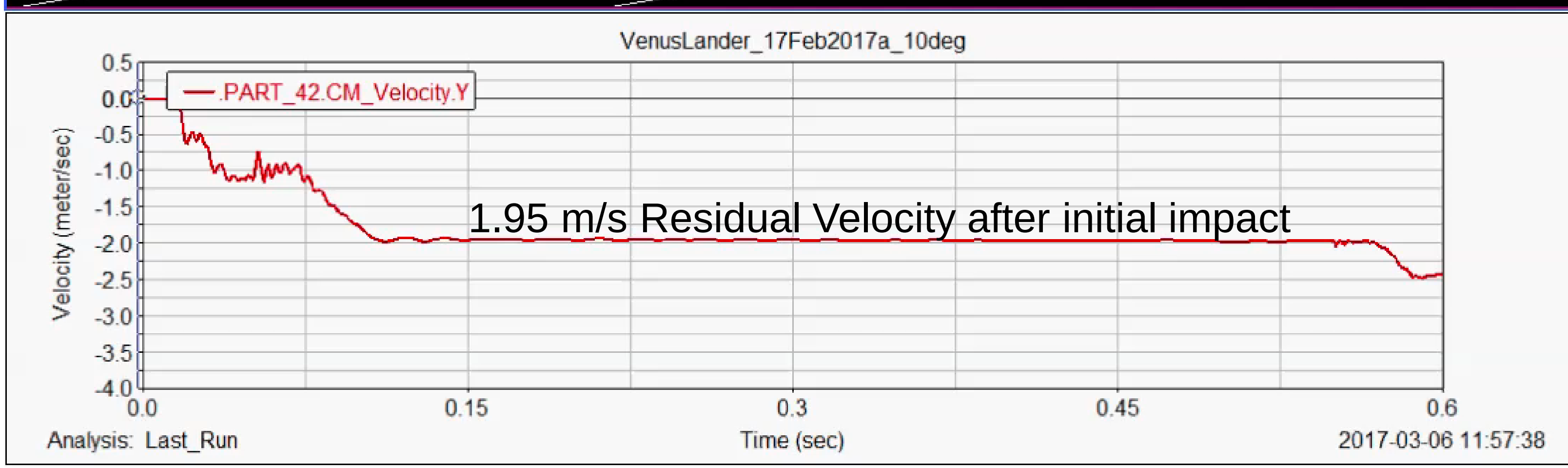
Case Study: Zero Slope; 3 (m/s) Lat.; 9.5m/s vert. Safe Velocity = 3.1





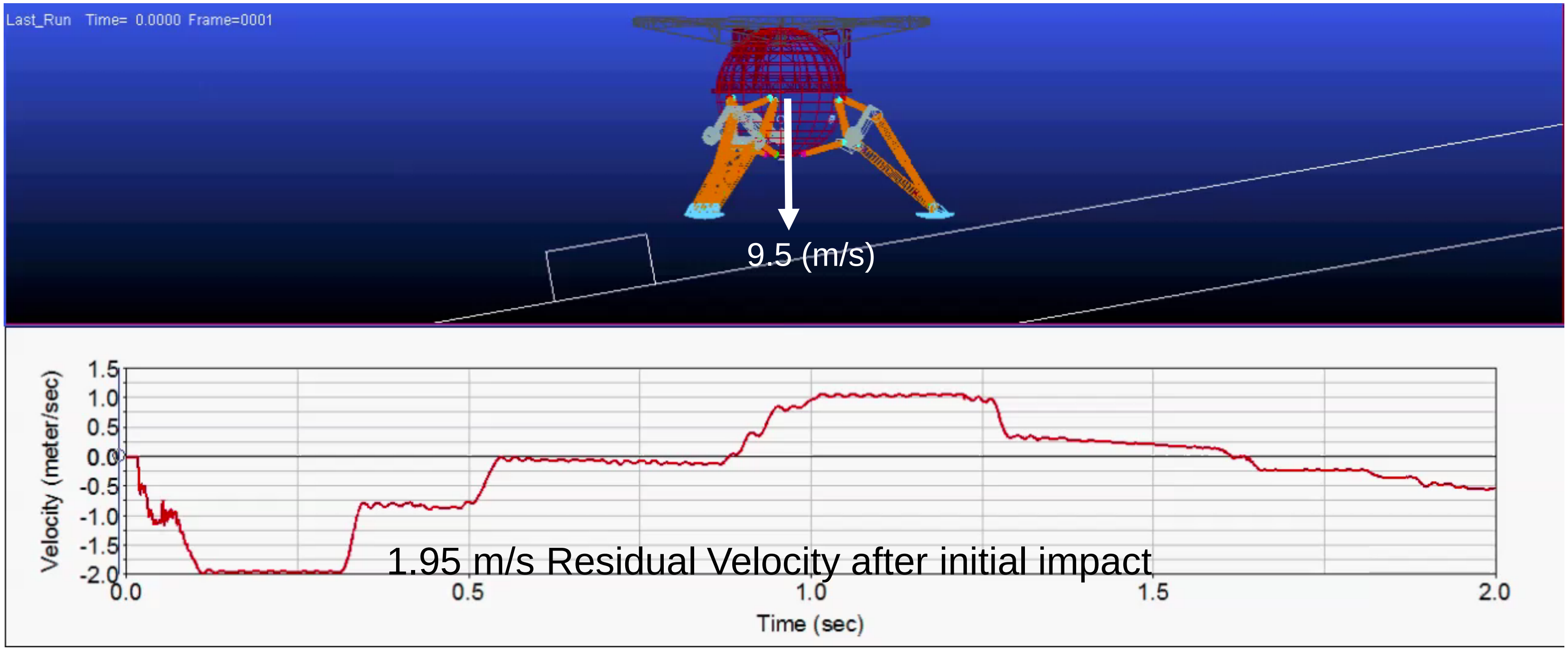
Case Study: 10 deg. Slope; No Hard Stop to Determine Residual Velocity from Momentum Transfer





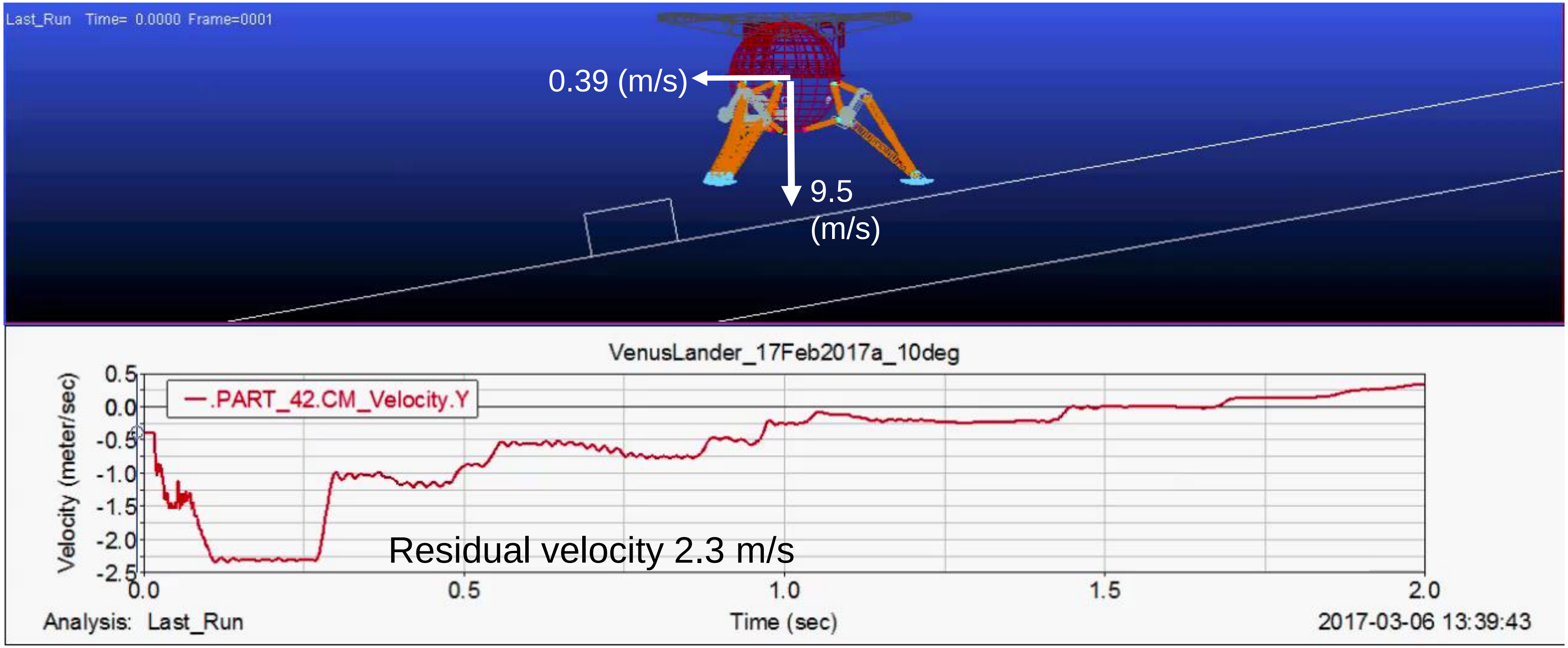
Safe Velocity on a 10 deg. Slope = 2.34 m/s

Case Study: 10 deg. Slope with Hard Stop
Vsafe = 2.34 m/s

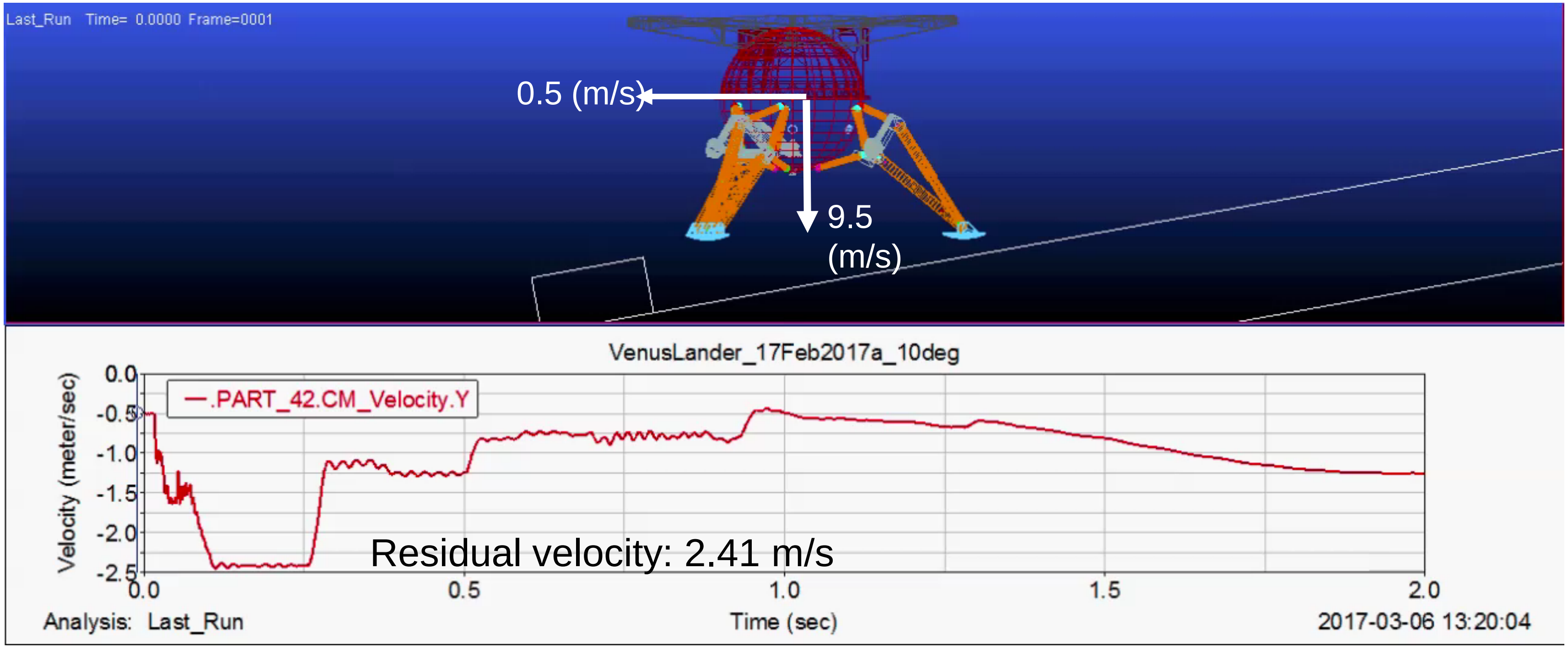


Margin for Lateral Velocity = 2.34 m/s – 1.95 m/s = 0.39 m/s

Case Study: 10 deg. Slope at 0.39 (m/s) lat. Safe Velocity = 2.34



Case Study: 10 deg. Slope at 0.5 (m/s) lat. Safe Velocity = 2.34



Margin for Lateral Velocity = 2.34 m/s – 2.41 m/s = -0.07 m/s

Conclusion

- For planetary landers, one measure of robustness to lateral impacts can be how much lateral velocity the design can tolerate for stability
- Lateral initial conditions are not sufficient to design to; lateral residual velocities from impacts must also be considered
- In addition to numerical means for accessing stability, analytical approaches can be used to determine and locate at what point the design fails for lateral stability

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Thank you